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Relay node placement to heal partitioned wireless sensor networks ☆

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ABSTRACT

The wireless sensor networks deployed in hostile environments suffer from a high rate of node failures. Such failures may convert a fully-connected sensor network into multiple disjoint sub-networks, leading to the network partition problem. The placement of relay nodes is the only way to restore the lost connectivity because these devices, compared to the sensor nodes, have a higher energy backup, with a longer communication range. In this paper, a new solution is proposed to heal the network partition problem in the wireless sensor network. The solution is based on a zero gradient point inside the convex hull polygon. The proposed solution is compared with various naive approaches, along with existing state-of-the-art solutions, that is, the Spider Web-1C heuristic and Steiner-minimum-tree based optimal relay node placement algorithm. The simulation experiment results confirm the effectiveness of our proposed approach.

1. Introduction

The wireless sensor networks (WSNs) have started playing an important role in the life of human beings through different applications. WSN applications such as combat field reconnaissance, border protection, space exploration, etc. operate in the harshest environments, resulting in reduction of risk to human life [1–3]. Since a sensor node is typically limited in its communication resources, a large count of sensor nodes is required to ensure full area coverage and further increase fidelity of the collected data [2]. Due to the small form factor and limited on-board energy supply, a sensor node is very much prone to failure and sometimes results in damage of the sensor nodes on a large scale, leading to the network partition problem in the network. Such a failure may convert a connected network into multiple disjoint segments. For example, some sensor nodes may be damaged after a snow or a sand storm or on the battlefield, a part of the deployment area may be attacked by the enemy explosives and, thus a set of sensor nodes in the vicinity may get destroyed (it is assumed that terrain is not destroyed) and the network gets converted into different disjoint sub-networks. For example, Fig. 1 shows a partitioned network after the failure of the large scale sensor nodes in the network. In this figure, eight disjoint segments are formed and represented by Seg_1 to Seg_8 in the partitioned WSN. The biggest challenge in such a type of scenario is to reconnect these disjoint segments with a small count of high power relay nodes. Therefore, repairing of such partitioned networks has become a current research area in WSN. A Relay Node (RN) is a more robust as well as a capable node with a significantly

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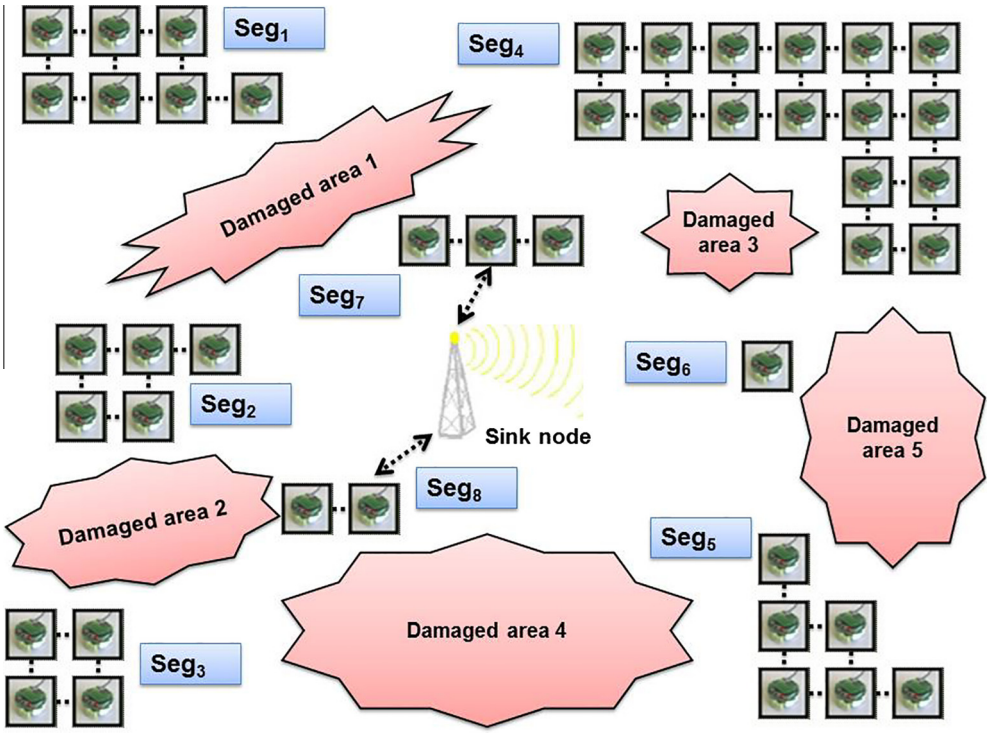

Fig. 1. Articulation of segmented area due to large scale failure of sensor nodes.

higher energy reserve and longer communication range (r) than the sensor nodes. RNs can, in principle, be equipped with sensor circuitry perform mainly the valuable data aggregation and data forwarding. Unlike sensor nodes, RNs may be mobile and can have some navigation capabilities. Therefore, RNs are preferred for network partition recovery because these nodes compared to sensor nodes are more easily and accurately placed in the disjoint sub-networks. Their radio range (r) is even higher, which can facilitate and expedite the lost connectivity restoration among the disjoint segments, effectively and efficiently. RNs being more expensive, a small count of RNs should be used for recovering the lost connectivity in the partitioned network. A small number of RNs can be found using the Steiner Minimum Tree with Minimum number of Steiner Points and Bounded Edge Length (SMT-MSPBEL), but it is shown to be an NP-hard problem for the large scale WSN [4,5]. Hence, a polynomial time solution is needed for an efficient recovery of the partitioned network. In this research paper, a similar type of network partition problem is considered and explored. The distinction of our proposedolution is that the network partition problem is addressed and solved by using a global zero gradient point inside the convex hull polygon, which has not been seen yet in any other published literature. In a similar work [14], the authors have considered a global minima based geo-cast routing technique for data dissemination to reduce data transmission distances between the nodes to enhance the network lifetime. However, the authors do not consider the network partition problem in their proposed solution, which is a very common problem in an unattended WSN. At the outset, our main contributions in this paper are:

1. Two naive approaches and two state-of-the-art heuristics are implemented along with our proposed solution to retrieve the lost connectivity of the partitioned WSN.
2. The proposed solution works perfectly for any number of disjoint segments without checking the angles between the edges of the disjoint segments which is a constraint in Discrete Fermat point based approach (i.e. SMT-ORC approach [5]).
3. The proposed solution is different from any other published partition recovery solutions (i.e. ORC-SMT, Spider Web-1C) because it considers global zero gradient point inside the convex hull polygon to find an optimal point for the placement of RNs, instead of taking three non-collinear disjoint segments at all times.

The remainder of the paper is organized as follows: In the next section, related work is described. Section 3 gives the problem statement and describes our system model. In Section 4, details about the proposed solution are given. In Section 5, pseudo code is shown and explained. Section 6 gives an overview of various proposed state-of-the-art approaches for comparison purpose. In Section 7, performance evaluation through simulation experiments is described to prove the usefulness of our proposed solution, followed by conclusion in Section 8.